ADA039234

AD No.
DDC FILE COPY

TM 77-1 RW

12 NW

# Technical Memorandum

A PROGRAM FOR INCREASED FLIGHT FIDELITY
IN HELICOPTER SIMULATION


LT C. Woomer, USN
Mr. D. Carico

Rotary Wing Aircraft Test Directorate




27 April 1977



NAVAL AIR TEST CENTER
PATUXENT RIVER, MARYLAND

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

14)

# REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NATC- TM 77-1-RW
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER

9

4. TITLE (and Subtitle)

6 A PROGRAM FOR INCREASED FLIGHT FIDELITY IN HELICOPTER SIMULATION.

5. TYPE OF REPORT & PERIOD COVERED: TECHNICAL MEMORANDUM

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

10 LT C. WOOMER, USN
MR. D. CARICO

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS

ROTARY WING AIRCRAFT TEST DIRECTORATE
NAVAL AIR TEST CENTER
PATUXENT RIVER, MARYLAND 20670

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

12 21 p.

11. CONTROLLING OFFICE NAME AND ADDRESS

NAVAL AIR SYSTEMS COMMAND
DEPARTMENT OF THE NAVY
WASHINGTON, D.C. 20361

11

12. REPORT DATE: 27 APR [redacted]77

13. NUMBER OF PAGES: 23

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

FLIGHT FIDELITY
SIMULATOR
AVIATION TRAINING DEVICE
FLIGHT TEST
HELICOPTER
VISUAL SYSTEM
OPERATIONAL FLIGHT TRAINER
WEAPON SYSTEM TRAINER

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Increased emphasis has been placed on the need for and usefulness of major aviation training devices - flight simulators. A description of a modern trainer and the status of current simulation is provided. High fidelity is necessary to achieve high training transfer to the aircraft. The authors describe the need for and a proposed basic approach to technical simulator flight testing designed to achieve high fidelity. Ideas were formulated as a result of the authors' participation in the development and validation of the SH-2F Weapons System Trainer, Device 2F106. NAVAIRTESTCEN participates in the program as next page

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)



246 750

20.

cont

a technical advisor on flight fidelity. Major contributions are aircraft testing for the establishment of criteria data followed by simulator evaluation, both performed by engineering test pilots and flight test engineers. These evaluations used established and disciplined flight test techniques and should be commonplace in the development and validation of flight trainers. An extensive table of criteria data tests is provided for reference. Typical instrumentation tables for both the aircraft and trainer are included. Specific comments are made concerning trainer testing problems and the priorities of tests. A discussion is included on simulator data-gathering techniques, appropriate parameters, and equipment needed. Finally, the scope of a visual system evaluation is presented, along with a description of its usefulness in additional testing of the basic trainer.

A

## PREFACE

This technical memorandum is the result of experience gained by the authors while on the SH-2F WST, Device 2F106 program. The paper was prepared for presentation 11 May 1977 at the 33rd Annual National Forum of the American Helicopter Society in Washington, D.C. No detailed guidelines presently exist for the engineering test pilot and flight test engineer involved with the development and evaluation of a helicopter training device. The contents of this memorandum have been reviewed by flight test and/or training device specialists at NAVAIRTESTCEN, NAVTRAEQUIPCEN, and industry.

APPROVED FOR RELEASE

J. H. Foxgrover

RADM J. H. FOXGROVER, USN
Commander, Naval Air Test Center

A Program for Increased Flight Fidelity
in Helicopter Simulation

LT C. Woomer, USN
Project Pilot
and
Mr. D. Carico
Project Engineer
Rotary Wing Aircraft Test Directorate
Naval Air Test Center, Patuxent River, Maryland

## Abstract

Increased emphasis has been placed on the need for and usefulness of major aviation training devices - flight simulators. A description of a modern trainer and the status of current simulation is provided. High fidelity is necessary to achieve high training transfer to the aircraft. The authors describe the need for and a proposed basic approach to technical simulator flight testing designed to achieve high fidelity. Ideas were formulated as a result of the authors' participation in the development and validation of the SH-2F Weapons System Trainer, Device 2F106. NAVAIR TESTCEN participates in the program as a technical advisor on flight fidelity. Major contributions are aircraft testing for the establishment of criteria data followed by simulator evaluation, both performed by engineering test pilots and flight test engineers. These evaluations used established and disciplined flight test techniques and should be commonplace in the development and validation of flight trainers. An extensive table of criteria data tests is provided for reference. Typical instrumentation tables for both the aircraft and trainer are included. Specific comments are made concerning trainer testing problems and the priorities of tests. A discussion is included on simulator data-gathering techniques, appropriate parameters, and equipment needed. Finally, the scope of a visual system evaluation is presented, along with a description of its usefulness in additional testing of the basic trainer.

## Background

The Department of Defense has proposed a procurement effort of over $800 million on flight simulators in the next 2 years (reference 1). This represents a resurgence of military interest in simulators spurred on, in part, by the fuel shortage of 1973. Prior to that, the airlines and NASA had made significant advances in flight simulation. The reduced cost of training in a simulator has often been presented as justification for its procurement. Other arguments are based on the increased amount of training made possible with a training device when compared with the limited aircraft assets available. The potential for regular 16 hr days in active training in the simulator causes quantum jumps in command productivity. However, the most dramatic result from the addition of a simulator such as the SH-2F Weapons System Trainer (WST), Device 2F106, is in the improved quality of training. Response to emergency situations, some of which are not practical for actual flight, can be learned and practiced in a high fidelity simulator. Realistic tactical military situations that are often impossible to establish in actual flight during peacetime can be encountered. The high fidelity of the performance and flying qualities of the device is essential to the realism required to adequately train for these missions.

There is a stigma associated with all flight trainers due to the varying degrees of poor fidelity provided by many. Grand claims and limited practical utility of even the most expensive trainers have led to repeated disappointments. Nevertheless, simulated flight time has been authorized as a substitute for actual flying experience. Concurrently, actual military flight time has, in many cases, been severely reduced. If the desired readiness is to be maintained, these new trainers intended to replace actual flight time must be capable of providing high training transfer. Increased flight fidelity is necessary to obtain this high transfer. Skills learned and practiced in a trainer can only be applied directly to the aircraft if adequate fidelity exists with the aircraft characteristics. A high fidelity flight trainer offers the potential for a variety of additional applications, such as accident investigation, the development of improved operational procedures, or the evaluation of proposed aircraft modifications. As a specific example, research such as the evaluation of new shipboard approach lighting could be economically accomplished in a validated high fidelity trainer. The utility of such a device is in many ways limited only by its availability and the imagination of the user.

## Purpose

Generally speaking, the procurement of major aviation training devices should be treated similarly to that of new aircraft. Specifically, the use of established and disciplined flight test techniques should be commonplace in the development and validation of these devices. The simulator manufacturer must be prepared to demonstrate predetermined levels of trainer fidelity with the aircraft data. Time, procedures, and necessary equipment must be planned into the development program to accomplish this goal. Airframe and aircraft subsystem manufacturers should be informed and responsive to the needs of the simulator manufacturers for specific design data and equipment. This requirement is often concurrent with development/production of the aircraft systems, due to the desire to use the trainer as the aircraft is introduced operationally. Significant coordination and cooperation, not to preclude commercial contracts, are required if the needs of the service are to be met. The purpose of this paper is to describe the need for and a proposed basic approach to technical simulator flight fidelity testing.

The proposed approach included here was formulated as a result of the authors' participation in the development and procurement of the SH-2F WST, Device 2F106. The program, completed in November 1976, produced exceptional flight fidelity for the Navy's first modern helicopter flight trainer and is being used at the Rotary Wing Aircraft Test Directorate as a guideline for future work. Selected data illustrating the fidelity obtained are presented in appendix A. Photographs of the trainer are contained in appendix B. Presently, a CH-46E Operational

Flight Trainer (OFT) and an SH-3H OFT are active projects with anticipation of RH-53D, CH-53E, and LAMPS MK III trainers in the future.

## Navy Trainer Procurement Team

The NAVAIRTESTCEN team is part of a larger group organized to ensure the success of a new trainer. A brief overview of the major participants in a Navy procurement follows. NAVAIR is charged with funding and overall program management. Close coordination is established with the Naval Training Equipment Center (NAVTRAEQUIPCEN), where a contracting officer and a program engineer are assigned. The program engineer provides working-level management of the acquisition. A Fleet Project Team (FPT) is assigned by the Office of the Chief of Naval Operations (OPNAV) through the appropriate operational commanders. This team usually consists of instructor pilots and aircrew from the eventual using activity such as the specific type training squadron. These individuals provide the invaluable contribution of current fleet experience with the particular aircraft. In the past, these pilots were erroneously expected to become instant experts on flying qualities and performance (FQ&P) evaluating. Today, in addition to extensive systems verification and qualitative flight testing, the FPT has the prime responsibility for directing the development of the instructor interface system based on its intended training requirements.

The eventual recipient of the trainer is the Fleet Aviation Specialized Operational Training Group (FASOTRAGRU). This organization is responsible for facility management, maintenance, and operational readiness of the device in support of the using activity. NAVAIRTESTCEN participation involves, as a minimum, a test pilot and engineer team to act as technical advisor to NAVAIR and the Program Engineer (NAVTRAEQUIPCEN) on FQ&P. The contractor team generally consists of a program manager, computer specialists, and various systems specialists including an aerodynamicist.

## NAVAIRTESTCEN Policy

The general guidelines for NAVAIRTESTCEN participation were established in coordination with NAVTRAEQUIPCEN and NAVAIR and are contained in reference 2. The major elements of that instruction are:

a. Establish liaison with the appropriate NAVAIR and NAVTRAEQUIPCEN personnel.

b. Provide assistance during specification preparation, proposal evaluation, and source selection phase.

c. Monitor the contractor's development.

d. Provide NAVAIRTESTCEN developed flight test data for incorporation in the trainer specification, for contractor baseline data, and as the standard for measurement of simulation fidelity.

e. Review math model, criteria report, and Acceptance Test Procedures and comment on their applicability.

f. Conduct Navy Preliminary Evaluations (NPE's) as required.

g. Participate in government in-plant acceptance tests.

h. Provide engineering and test pilot assistance in adjusting hardware and software programs to achieve proper flight fidelity.

i. Participate in government on-site acceptance tests.

j. Participate in validation of subsequent trainer units during in-plant and on-site acceptance.

k. Conduct periodic follow-on tests and evaluations to assess the effects of design changes.

l. Prepare reports of flight fidelity evaluations for distribution to NAVAIR, NAVTRAEQUIPCEN, and the training device contractor.

The policy contained in this instruction has been successfully applied to several fixed-wing and rotary-wing programs. NAVAIRTESTCEN participation is best utilized from the earliest evolutions including preparation and review of requirements, proposals, and specification documents through final acceptance.

## Typical Milestones

The usual milestones of an acquisition program for a training device are included here for general information. This description applies when NAVTRAEQUIPCEN acts as the procuring activity; in some situations, NAVAIR acts directly as the procuring activity. A document defining an operational requirement is generated in OPNAV. Interested parties are convened by NAVAIR and NAVTRAEQUIPCEN to produce a document entitled "Military Characteristic," which specifically describes the features that would be required to accomplish the desired mission. After receiving authorization from NAVAIR, NAVTRAEQUIPCEN creates a detailed specification and solicits proposals from interested contractors. Source selection is based on the evaluation of these proposals. A contract is made through NAVTRAEQUIPCEN with the selected manufacturer. The contract usually includes an integrated logistics support package and numerous deliverable data items, such as math model, design, data, facilities, and test procedures reports in addition to the trainer itself. Several NPE's precede the in-plant acceptance of the device. Government in-plant acceptance tests are conducted on the complete system to determine if it is ready for fleet delivery. Following this acceptance, the device is disassembled, relocated at the designated training facility, and reassembled. Government on-site acceptance testing is conducted prior to formal acceptance of the trainer. Following this final acceptance, specific hardware and software changes continue throughout the useful life of the trainer to improve it and maintain a comparable configuration with the fleet aircraft. Annual verification of trainer fidelity is also conducted.

## Modern Trainer Description

Modern trainers such as Device 2F106 are characterized by an exact replica of the cockpit and crew station containing functional and, in some cases, actual aircraft equipment. Flight control, navigation, communications, and weapons systems are modeled in addition to most other aircraft systems. A full 6-deg-of-freedom motion base is hydraulically powered and driven by computer-generated commands. Some fixed-wing trainers meet their requirements with less than the 6-deg-of-freedom motion system; however, helicopter and other Vertical Takeoff and Landing (VTOL) applications specifically use this full-motion system to adequately simulate low-speed flying qualities. A full range of aircraft vibrations for normal and emergency situations adds to the simulated environment as a result of the programmable motion system. Sound systems electronically generate air-rush, rotor, engine, and accessories' noise into the cockpit. Various types of visual systems can accurately present spatial information to the pilot. Moving targets, such as ships and other aircraft; functional lighting systems, such as glide-slope indicators and strobe lights; and detailed geographic features are routinely included in visual scenes. Instructor stations provide interactive displays and dedicated controls for manipulation of mission configuration, malfunctions, environment, and communications. Instructor-assistance features normally include demonstrations, exercises, checkrides, audio recordings, ground-track displays, and automatic initialization capabilities.

Subsystems and assistance features are linked together and function simultaneously in real-time via the digital computation system. Simulated aircraft systems, trainer systems, environmental programs, and executive programs create great demands on the general-purpose digital computer. The flight dynamics program is very extensive and is the major concern in improving flight fidelity. Numerous other systems are cued from the flight dynamics program, including all instruments, the sound and motion systems, and the visual system. Flexibility must be designed into this program in order to later refine the FQ&P fidelity. Computational speed and accuracy, particularly for the flight dynamics program, are imperative if satisfactory flight fidelity is to be attained. Iteration rates of 16 or 20 Hz appear to be the minimum acceptable for this purpose.

The complete operational flight envelope of the aircraft can and should be simulated with high fidelity. This eliminates training restrictions and allows the trainer to be used for various mission-related tasks. In some cases, simulation should go beyond the normal flight envelope, for example, the demonstration of departure characteristics (fixed-wing) or blade stall (helicopter).

## Flight Data Requirement

An extensive data base is required to ensure that the level of fidelity is sufficient throughout the flight envelope. In the past, Navy test programs did not produce sufficient mid-envelope aircraft data for trainer development. Sophisticated data collection systems now generally employed for new aircraft testing have reduced this problem. However, a requirement for additional aircraft flight testing in support of the trainer development has been the general rule. This is particularly true when dealing with an older in-service aircraft that may have undergone evolutionary changes in design. Past reliance on wind-tunnel and theoretical stability data and uninstalled engine performance data has resulted in marginal fidelity. In helicopter simulation, the classical aerodynamic solutions are not as well defined as in fixed-wing aircraft or rocket-powered vehicles. In general, the data requirements for trainer development are classified into two categories: design data and criteria data. Design data are required elements such as weight and balance, cockpit layout, structures, wiring logic, fuselage and rotor system physical characteristics, wind-tunnel estimates, moments of inertia, etc. Much of this type of data is commercially available to the simulator manufacturer. Criteria data are generally those provided by NAVAIRTESTCEN through test and evaluation.

A typical matrix of criteria data tests is presented in appendix C. The presentation includes a list of required tests, appropriate data presentations, and specific comments. This is a general outline intended to be modified as necessary to meet the needs of a specific aircraft configuration or mission. The data base should be extensive enough to provide parameter isolation as much as economically possible. This procedure will allow simulator program changes to be less random, more effective, and more timely. Due to the detail of simulation, it is necessary to obtain data that interrelate systems such as the rotor, engines, flight controls, and airframe. The most obvious example would be in slow-speed, low-altitude flight characteristics where the environment, performance, and flying qualities interrelate significantly. This may be the most challenging area of helicopter simulation due to its mathematical complexity. Criteria data should be gathered for each system simultaneously in order to establish proper relationships in the simulation.

Flight test data must be extensively documented. Known factors, such as aircraft configuration, gross weight, CG, pressure altitude, air temperature, wind, and all normal flight test parameters, must be identified for each test. When repeating the test in the simulator, these factors are assigned values as recorded during the aircraft test. In this manner, variables between the aircraft and simulator tests are minimized and data obtained are comparable.

## Aircraft Testing

The aircraft testing necessary to provide these criteria data should be done using standard flight test techniques (references 3 and 4) by a trained test pilot. It is highly desirable to have the same team perform both aircraft and simulator evaluations. This assignment policy ensures maximum efficiency in technique and data transfer, as well as flexibility in further testing that may be required. In addition to these advantages, criteria data provided by a government agency such as NAVAIRTESTCEN are objective and not influenced by specification guarantees and design goals. Simple "hand-held instrumentation" and "kneeboard-recorded data" provide flexibility in assessing several aircraft. This method is particularly useful for mechanical characteristics and some static tests. However, the required precision of flight test data demands much more reliable and [illegible]nth technical data gathering. Significantly improved fidelity requires a serious effort to obtain detailed criteria data, particularly in flight dynamics. For instance, time histories of angular acceleration and rate are more useful than the resultant attitude. An instrumented aircraft of the appropriate configuration is necessary. A typical instrumentation package is detailed in appendix D, table I. The aircraft should be provided early in the program so that data may be obtained, processed, and provided to the contractor without causing program delays. These data may then be incorporated in appropriate documents such as the criteria report and acceptance test procedures. In this manner, the standards for acceptance will have been established for the simulator evaluations to follow.

## Simulator Testing

Evaluation of the training device for FQ&P fidelity should be accomplished by a trained test pilot using standard flight test techniques as in the aircraft. This has seldom been done in trainer programs except by NAVAIRTESTCEN in accordance with its current policy. It is in sharp contrast with most previous programs in which the trainer manufacturer selected the appropriate data and determined the test methods which were then accomplished by the contractor or the FPT. Today, the trainer evaluation is nearly identical in scope to that of the aircraft as presented in appendix C. A very large portion of the effort is devoted to control-response testing and validation of the flight dynamics. In some tests, limitations to standard procedures are encountered due to an incomplete environment, i.e., the lack of a visual system when attempting visually referenced test methods. In this case, modified procedures need to be developed to provide the information usually obtained from visual reference. If possible, the modified test techniques should be evaluated in the aircraft and test results compared with those from standard test techniques. An example of this problem is encountered in lateral-directional statics while attempting steady-heading sideslips. In this test, a visual reference is customarily used for turn rate. The turn-needle presentation to the pilot can also be used; however, it is not nearly as accurate as a properly planned visual reference. In the simulator, turn rate is computed very accurately. This more precise value can be displayed on the instructor's console. With some coordination, turn rate as displayed can be included in the now combined scans of the test pilot and instructor and used as the quality factor for the data point as in the aircraft. Other examples of modified techniques include using Doppler readouts of drift angle and ground speed for establishing precise hover or translation sideward, rearward, or slow forward for trimmed-control positions. On simulations without Doppler, the display of orthogonal velocities on the instructor's console would suffice. Altitude hold features of the aircraft or the use of a single parameter freeze capability in the trainer assist in obtaining in-ground effect (IGE) data points where pilot workload may be excessive without a visual reference. Doppler information or velocity readouts can also be used for vertical climb performance tests when a visual reference is not available. It is hard to imagine a case where digital or analog information could not be monitored real-time to compensate for unavailable cues during tests. These particular problems need to be identified early and appropriate solutions planned for.

During simulator testing, evaluators must be prepared to recognize pilot adaptability to the flying qualities of the simulator. This is likely to occur when performing a unique task such as hovering and when other cues are not available. A pilot can quickly develop the necessary scan and technique to perform a precise task, overcoming gross fidelity deficiencies. Other contributing factors are the potential for many hours of flight time in the simulator while concentrating on a single problem area and the lack of recent aircraft flight time for the test pilot while at the contractor's facility for extended periods. To combat the latter, arrangements should be made, if practical, for concurrent aircraft flight time while the pilot is assigned to the trainer program. However, quantitative tests should be designed wherever possible to minimize reliance upon qualitative assessments that may be influenced by incorrect or incomplete environments.

Pilot performance and qualitative opinion have been observed to markedly improve with the addition of major subsystems that provide motion, aural, and visual cues. This is a testimony of their necessity in training, but a caution that during evaluations their absence or uncorrected false cues may affect test results. A subtle example of this type of problem occurs when using the visual display for a ground reference, but the effects of a more limited field of view such as increased workload are not considered. The need for qualitative testing remains significant, but more attention to test design is required in the trainer than in the aircraft if the results are to be meaningful. The assistance of the FPT pilots should be stressed when considering qualitative tests. Specific debrief by the NAVAIRTESTCEN team may lead to definition of problems and quantitative testing based on their observations.

One area where only qualitative simulator flight testing is presently being done is in the evaluation of the motion system. Criteria data for vibration characteristics are used, but the final tuning remains qualitative. Engineering tests are being conducted to evaluate the response characteristics of the system and its individual servoactuators. The results confirm the mechanical quality of the motion system but have no direct relationship to its effect on the simulator pilot. Currently, there are more than a dozen different sets of algorithms in use for motion system integration to the simulator flight dynamics. NASA and NAVTRAEQUIPCEN are working toward optimization in this area. Several other studies are underway to determine the suitability of motion systems for providing onset cues. Speculation ranges from the elimination of motion systems altogether to using them for static attitudes while providing onset cues with a controlled seat device. Research on this subject should prove highly beneficial. The strong interrelationship between motion and visual cues and their importance in flying helicopter-VTOL-type aircraft requires close evaluation of their respective system performance.

A building-block approach is necessary to establish a logical test sequence. Early evaluations may be restricted to a few operational systems. In general, the following priorities should be established. Test instrumentation must be calibrated and all sources of data output verified. This includes validation of all normal cockpit instrumentation. Next, control system mechanical characteristics should be established. At this point, standard aircraft checklists provide appropriate test procedures for basic cockpit evaluations. Static performance and flying qualities necessarily must precede dynamic evaluation and adjustment. This same build-up approach should be applied to basic airframe characteristics followed by increasing levels of AFCS compensation. Motion system checks should be performed next, followed by visual system validation. Extensive testing should be devoted to mission-related tasks at the conclusion of this sequence. These priorities are not intended to limit the conduct of evaluations. However, consideration must be given to the total effect of changes made, including the validity of any results previously obtained.

## Simulator Data

A number of specific data-gathering techniques have been established for the simulator. Aircraft test conditions can and should be matched exactly for each test in the trainer. The capability to instantaneously stop the computer update of selected parameters or all flight dynamics leads to what has been termed a "freeze" function. By the judicious use of "freeze" and the preestablished and recallable "initial condition" function, the process of data gathering can be dramatically accelerated. In addition to cockpit data, preselected parameters can be digitally presented on the instructor's Cathode Ray Tube (CRT) display to provide essentially on-board instrumentation. Line printers or x-y plotters, if part of the installation, may be used to provide hard copy of CRT displayed data or could be programmed to plot static data. For dynamic data in helicopter simulators, there is a need for multiple channels of analog data. As a minimum, control positions, attitudes, rates, and accelerations are required. Individual parameters should be verified to be suitable for comparison to the aircraft data. For example, control positions should be monitored at the same location as in the aircraft. Inherent lags in the aircraft control system are not accounted for if the simulator control parameters are provided from the rotor system module. The channels need to be accessible through a single terminal board wired to the digital-to-analog converters. Analog recording devices are connected to this terminal for real-time simultaneous display of each selected parameter. Immediate analysis of program modifications can often be provided with this setup. A simple utility program for simultaneous calibration of all channels has proven to be a great time saver. For automated data processing later by the computer facilities at NAVAIRTESTCEN, a tape-recording system can be simultaneously connected to the same terminal. A summary of typical trainer "instrumentation" is presented in appendix D, table II.

If properly planned and programmed, the outputs of these simulator monitoring systems can provide comparable data format to that provided by any airborne instrumentation used. Identical paper speeds and parameters scaling are obviously necessary for direct comparison of data. Early consideration must be given to the characteristics of parameters when selecting data format, i.e., when attempting modifications to acceleration onset in tenths of a second, the minimum desirable paper speed is 10 mm per second. With these systems, it is possible to monitor sufficient parameters to isolate individual problems and determine the effects of changes. What results is an iterative process to correct/improve the fidelity of specific parameters. Aircraft data should be available and organized in a ready reference system for immediate access. Sufficient time must be given to analysis of appropriate data to provide an engineering approach to progressive changes. Development sessions quite often require the NAVAIRTESTCEN team to provide testing and evaluation expertise in support of the contractor. These government-supported development efforts should be limited in duration and scheduled only after the contractor has made sufficient progress with his own capabilities to warrant it. Specific milestones should be jointly established by the contractor and government representatives as a prerequisite to this type of effort.

Evaluations to determine progress and current status of the fidelity, such as NPE's and acceptance tests, must be conducted on a fixed configuration. No changes should be made during these evaluations, since all effects due to the change may not be immediately obvious. For example, changes to accessory loads for rotor engagement and disengagement characteristics may seem isolated, but autorotation performance is directly affected. All test results in the simulator must be identified to a specific software configuration. It is essential that the contractor provide this information and adhere to rigid administrative procedures to control and document program changes and reassemblies. It is equally as important for the evaluators to adequately identify and catalog the voluminous amount of data generated.

## Reporting Procedures

Deficiencies must be formally reported as they are discovered. Current policy is for the program engineer to collect, organize, and prioritize all Discrepancy Reports (DR's) on standard forms provided by NAVTRAEQUIPCEN. A single master log of these reports is thereby maintained. For technical deficiencies, it is necessary to provide, as part of the DR, copies of appropriate data to fully describe the problem. DR's are furnished to the contractor immediately for corrective action. Following each evaluation, or as appropriate, NAVAIRTESTCEN submits reports directly to NAVAIR by message in Project Situation Report format. These reports are temporary by design and describe the latest documented status. Final documentation of the trainer's flight fidelity is provided by NAVAIRTESTCEN by formal report.

## Visual System

Of particular interest is the evaluation of visual systems. It is important to recognize that the visual system dramatically illustrates basic program weaknesses, as well as its own. As in the aircraft, visual cues are overriding to the pilot. Unstable visual presentations are capable of nauseating pilots within minutes as a result of the strength of the visual cue. Visual systems can be made to accurately track the host program and still not be suitable for training. In this case, modifications to the basic trainer program are required. It is best to start visual system integration only after the basic program has been brought to a reasonable level of fidelity and has been well documented. Experience has shown that trainers intended to have visual systems should not be accepted on the assumption that visual system integration will not require basic program modifications. Evaluation logically begins with the installation. Independence of the visual system from motion system inputs, shielding of projectors, and simple cockpit "light leaks" need to be checked. The scene content can then be addressed. This includes verification of designed runway layouts, targets, ships, landing pads, lighting systems, etc., for accuracy and detail in each scene. Individual display shading and intensity should be evaluated concurrently with scene content. Registration is the term applied to alignment of a multiple window visual presentation and is essentially a spherical geometry problem. The effect of a horizon sloping in a forward presentation while level in a sidelooking presentation can cause pilot disorientation. Synchronization applies to the coordination problem resulting from a multiple visual computer installation when the scan rates of input data are not identical. The perception of this problem occurs in turns (for a side-by-side installation) as an alternating shift in scene content by the two displays. Both registration and synchronization should be carefully evaluated.

Static alignment and attitude checks are normally done as part of the visual systems normal maintenance check. However, dynamic accuracy is necessary if the system is to be considered satisfactory for training. A calibrated signal representing visual attitude in each axis must be established. This signal should originate as close to the actual display as possible. By displaying simulator attitude and visual attitude on the same recording device and performing single-axis control inputs, visual dynamic response can be quantitatively evaluated. Control inputs should consist of both reversals and steps. Attitude displacement is easily compared. System lags are presented as the response delay measured between simulator and visual attitudes. The time lag which must be minimized is made up of simulator computation, data transfer, visual system computation, and display requirements. Minimum lags are necessary to preclude pilot-induced oscillations, particularly while attempting to perform closed-loop tasks such as hovering. Simulator response to control inputs should have previously been validated so that testing is now directed toward the visual system fidelity.

After the visual system is validated, it may be used as a tool for further evaluating and improving specific areas of the flight dynamics program. In general, these areas relate to ground reference maneuvers such as takeoff, landing, and autorotation. The evaluation of ground-handling characteristics requires the use of a visual system. Landing gear reactions, steering, braking, turning, and skidding are each considered. Many mission-related tasks, such as shipboard approaches and landings, can now be evaluated. Extensive qualitative tests should be performed using all scenes, multiple maneuvers, and specifically employing each means of problem control. This is necessary to ensure that the various modes and controls do not affect the fidelity of the presentation. In particular, scenes that present relative motion, such as between a moving ship and the aircraft, or ship motion due to sea state that feeds back to the aircraft, must be closely evaluated. Minor control logic differences or nonmatched update rates can cause very significant problems that are not evident without the visual system.

Because of the strength of visual cues, it is important to consider the planned trainer mission when deciding on the FOV to be presented. Ultimately, an identical FOV to that of the aircraft is desirable. Until such time as the state-of-the art can provide this capability, a trainer limitation is being created. In helicopter trainers, the absence of the lower few degrees of FOV is very serious. Normal vision cues used for precise hovering and landing are not present. Pilot compensation must be made by interpreting distance cues. This can be done on shore-based scenes or large-deck ship scenes, but it is impossible on small-deck ship scenes where the entire deck may be out of view due to "window" location. In general, VTOL/helicopter trainers should be provided with maximum coverage in the lower segments of FOV. Tradeoffs, if necessary, should be based on well-defined mission needs. Flight testing should be conducted to optimize window location. Various configurations of restricted FOV should be evaluated for effects on pilot workload.

## Conclusions

The renewed interest in flight simulators is based on their potential to reduce costs while increasing the amount and quality of aviation training. High fidelity flight simulators are necessary if the desired training transfer is to be achieved. The approach to trainer development and validation presented in this paper led to the accomplishment of that goal in the SH-2F WST program. The basic concept of this approach is that flight trainers should be evaluated like aircraft by engineering test pilots and flight test engineers. Extensive criteria data must be provided from an instrumented aircraft of the appropriate configuration. Testing of the aircraft for criteria data and of the trainer for fidelity should generally follow the program outlined in this paper. Engineering evaluation of the trainer data is mandatory if the advantages of this program are to be realized. The test techniques used during the trainer evaluation should be identical to those used in the aircraft. In those cases where limitations to normal testing occur, modifications must be designed to provide comparable data. Trainer evaluators readily adapt to deficient simulator flying qualities. Tests designed to produce quantitative results minimize this problem. In addition, concurrent aircraft flight time is highly recommended. The effects of major subsystems such as motion, sound, and visual must be carefully considered when determining test sequence. A trainer data plan that includes output techniques and recording devices is a basic element of this approach.

The comparison of trainer and aircraft flight test data when properly analyzed provides an engineering approach to trainer software adjustments. The result of this process is a flight trainer that exhibits the FQ&P characteristics of the aircraft. The benefit derived is a flight trainer usable throughout the aircraft envelope that is limited only by its availability and the imagination of the user.

In the future, government requirements for trainer fidelity will undoubtedly become more stringent. A program such as described in this paper will receive wide acceptance and result in increased testing performed on trainers to meet that goal. Manufacturers of trainers would be aided by this program by receiving more definite guidelines, specific criteria data from current flight tests, and simulator flight test data on which to base modifications. As flight dynamics research continues and math modeling and simulator implementation improve, the iterative testing and modifying currently necessary would be reduced. The ultimate justification would then be a vastly improved trainer at minimal development cost.

## References/Related Articles


1. Allen, Dr. J. L., Deputy Director of Defense Research and Engineering, "The Coming Payoffs of Improved Flight Simulators," Commanders Digest, Vol. 19, No. 16, of 29 July 1976.

2. NAVAIRTESTCEN Instruction 3960.12, Policy for Test and Evaluation of Major Aviation Training Devices, of 20 November 1975.

3. Helicopter Stability and Control, USNTPS FTM No. 101, of 10 June 1968.

4. Helicopter Performance Testing Manual (HPTM), USNTPS FTM No. 120, of 28 June 1968.

5. Aronson, M., "A New Approach to the Evaluation of Visual Attachments to Flight Simulators," Proceedings of the Sixth NTEC/Industry Conference, of November 1973.

6. Catron, R. L., LTC USA, Armor, Project Director, SFTS Program Army Training Device Agency, Orlando, Florida, "A New Approach to Flight Simulator Acceptance," U.S. Army Digest, of April 1976.

7. Cooper, Harris, Sharkey, "Effects of Visual System Time Delay on Pilot Performance," Proceedings of the Eighth NTEC/Industry Conference, of November 1975.

8. Galloway, R. T., NAVAIRTESTCEN, "Maximizing Flight Fidelity: Integration of Naval Air Test Center Capabilities into the Procurement of Major Aviation Training Devices," Proceedings of the Ninth NTEC/Industry Conference, of November 1976.

9. Gum, D. R. and Albery, W. B., Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, "Time-Delay Problems Encountered in Integrating the Advanced Simulator for Undergraduate Pilot Training," Vol. 14, No. 4, Journal of Aircraft.

10. Healy, L. D. and Cooper, F. R., "Verification of Simulator Performance by Frequency Response Measurement," Proceedings of the Sixth NTEC/Industry Conference, of November 1973.

11. Hewett, M. D., CDR, USN, NAVAIRTESTCEN, Galloway, R. T., NAVAIRTESTCEN, and Murray, J. C., CDR, USN, NAVAIRTRACOM, "On Improving the Flight Fidelity of Operational Flight/Weapons System Trainers," Proceedings of the Seventh NTEC/Industry Conference, of November 1974.

12. Jacobs, R. S. and Roscoe, Dr. S. N., "Simulator Cockpit Motion and the Transfer of Initial Flight Training," Proceedings of the Eighth NTEC/Industry Conference, of November 1975.

13. Kraft, Dr. C., Elworth, Dr. C., Anderson, C., and Allsopp, W., "Pilot Acceptance and Performance Evaluation of Visual Simulation," Proceedings of the Ninth NTEC/Industry Conference, of November 1976.

14. Matheny and Wilkerson, Human Resources Research Organization, "Functional Requirements for Ground Based Trainers - Helicopter Response Characteristics," HUMRO Technical Report 70-17.

15. Modrick, Dr. J., "Concept of Performance Specification and Its Role in Design of a Training Device," Proceedings of the Eighth NTEC/Industry Conference, of November 1975.

16. Ricard, G. L., Norman, D. A., and Collyer, S. C., NTEC, "Compensating for Flight Simulator CGI System Delays," Proceedings of the Ninth NTEC/Industry Conference, of November 1976.

17. Richmond, James A., Major USAF, Aeronautical Systems Division, Wright-Patterson Air Force Base, "Verisimilitude Testing: A New Approach to the Flight Testing of Air Force Simulators," Proceedings of the Ninth NTEC/Industry Conference, of November 1976.

18. Rust, S. K., CAPT USAF, "Flight Simulator Fidelity Assurance," Proceedings of the Eighth NTEC/Industry Conference, of November 1975.

19. Sealy, D. L., "Simulator Performance Validation and Improvement through Recorded Data," AIAA Paper No. 73-938.

20. Streiff, H. O., "Study, Survey of Helicopter and V/STOL A/C Simulator Dynamic Response," NAVTRADEVCEN Technical Report 1753.

21. Thielges, J. R. and Matheny, W. G., Human Resources Research Organization, "Analysis of Visual Discrimination in Helicopter Control," HUMRO Technical Report 71-13.

22. Vorst, C. J., MDEC, "A New Visual Simulation Technique for Pilot Training," Proceedings of the Ninth NTEC/Industry Conference, of November 1976.

23. Woomer, C., LT, USN, Rotary Wing Aircraft Test Directorate, "SH-2F WST Program," NAVAIRTESTCEN TEST TALK, of May 1977.

# APPENDIX A

## Selected Data

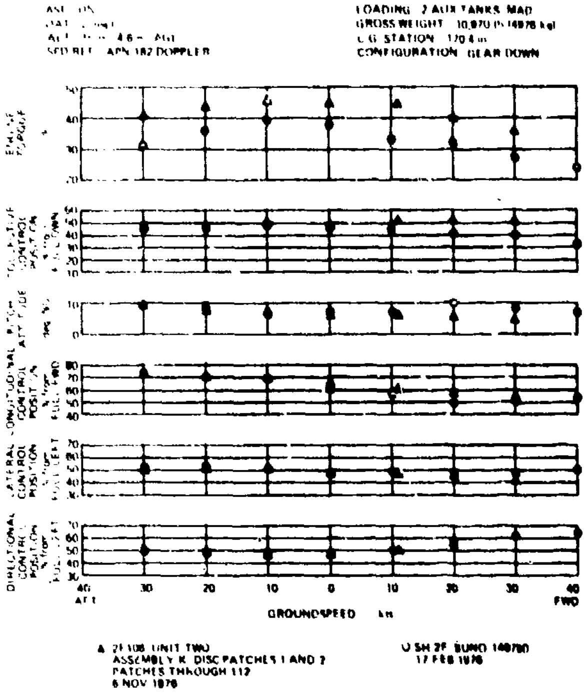


**Figure 1**
**Low Speed Trimmed Control Positions**

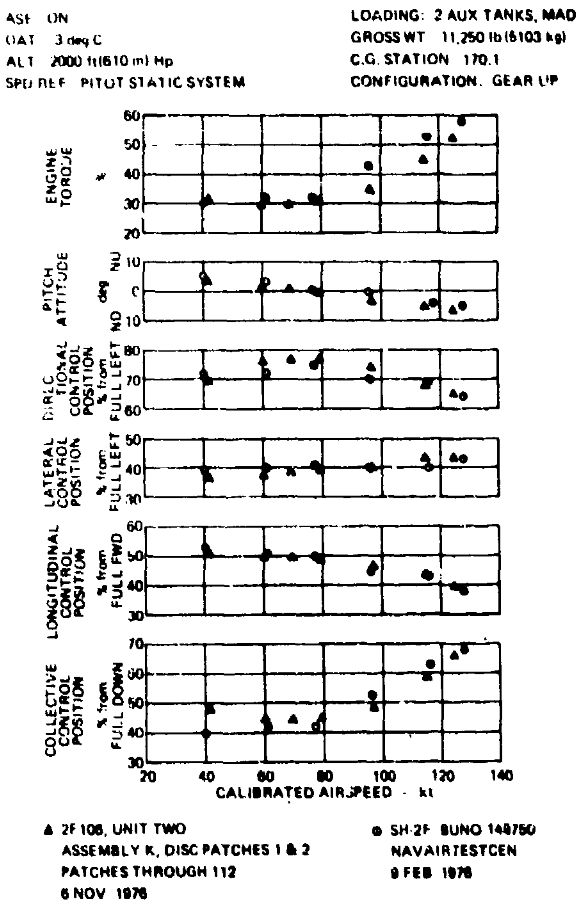


**Figure 2**
**Forward Flight Trimmed Control Positions**

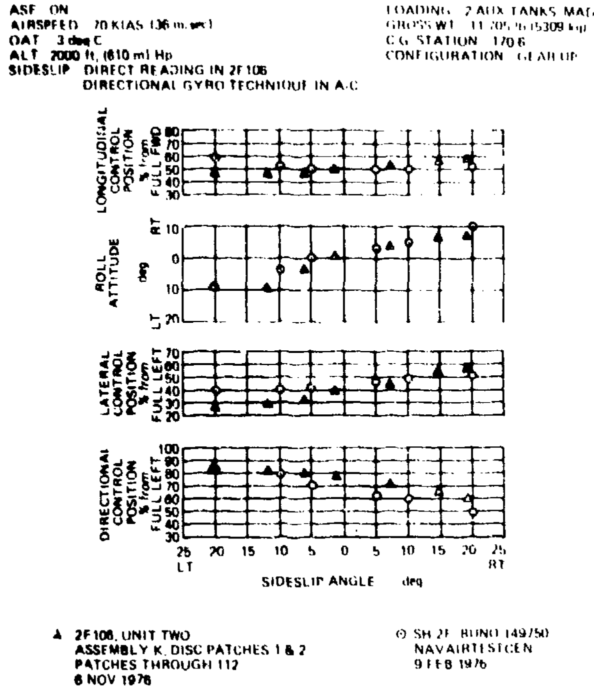


**Figure 3**
**Static Lateral-Directional Stability**

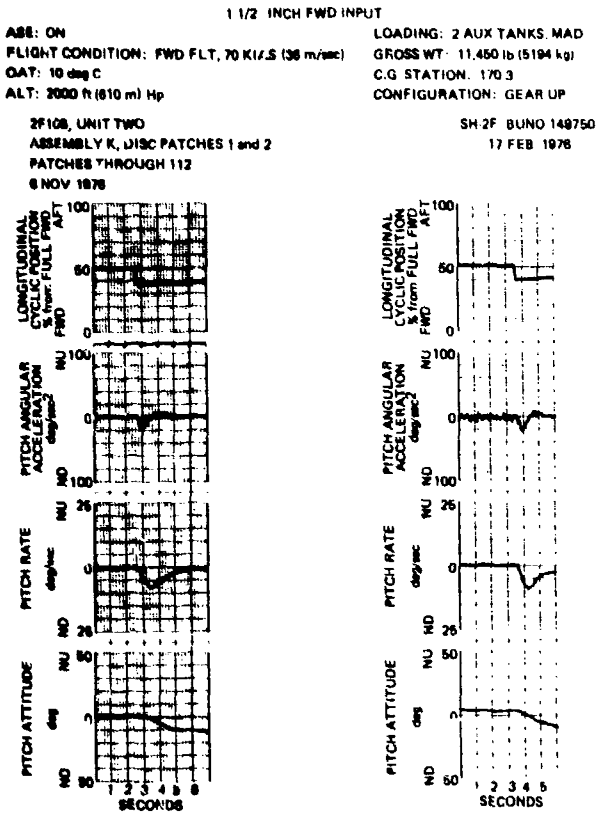


**Figure 4**
**Pitch Axis Control Response**

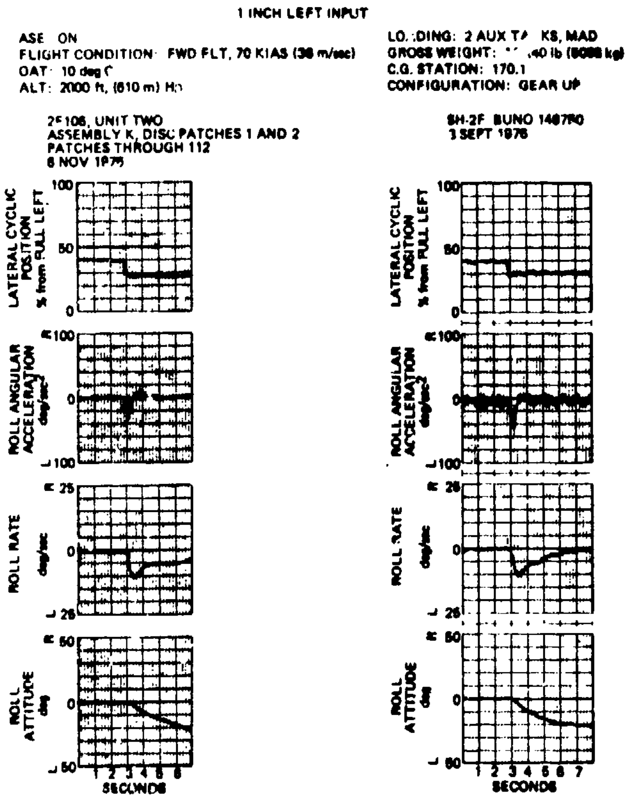


**Figure 5**
**Roll Axis Control Response**

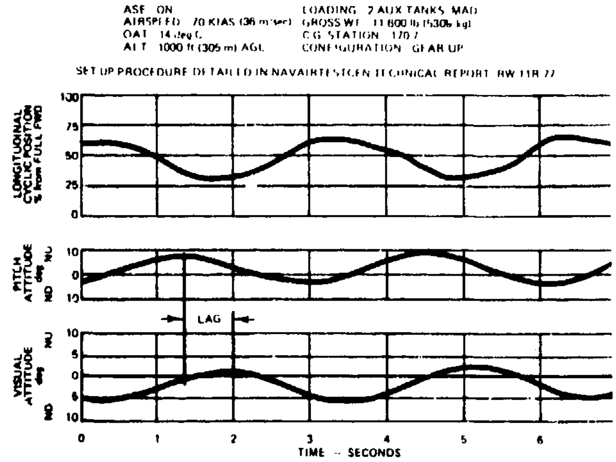


**Figure 6**
**Dynamic Visual System Response**

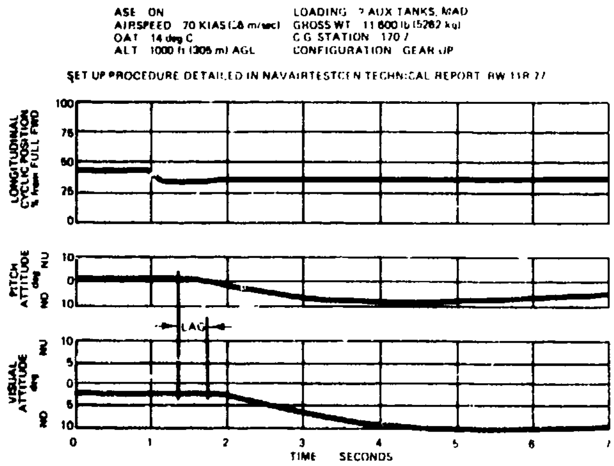


**Figure 7**
**Dynamic Visual System Response**

## APPENDIX B

**Photographs**

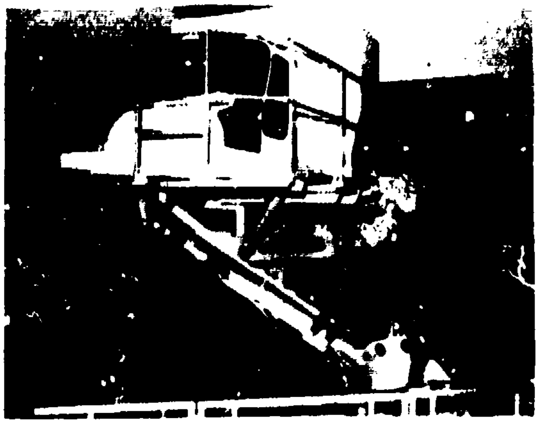

**Figure 1**
**SH-2F Weapons System Trainer**
**Device 2F106, Unit One**
**NAS Norfolk, Virginia**
**March 1976**
**Prior to Visual System Installation**

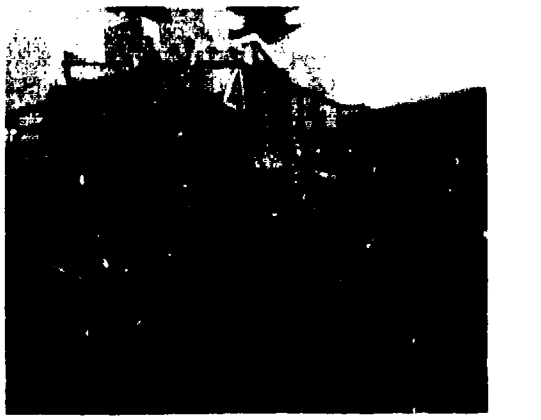

**Figure 2**
**SH-2F Weapons System Trainer**
**Device 2F106, Unit One**
**NAS Norfolk. Virginia**
**July 1976**
**Visual System Installed**

## APPENDIX C

### Tests for Establishment of Criteria Data in Aircraft and Simulator

| Test | Data Presentation | Remarks |
|---|---|---|
| Weight and Balance | Gross weight<br><br>Longitudinal, lateral and vertical CG<br><br>CG variation with fuel burnoff<br><br>Static aircraft attitude | Verify aircraft loading configuration. |
| Control System Mechanical Characteristics | Total control travel<br><br>Control free play<br><br>Breakout forces<br><br>Control force gradients and hysterisis<br><br>Control centering<br><br>Trim system lags and trim rates<br><br>Control system dynamics<br><br>Control system coupling | Control system mechanical characteristics should be determined on several aircraft to get a good data base.<br><br>Pilot qualitative comments on boost or hydraulic system-off control displacements and force gradients should be recorded.<br><br>Trim rates should be determined as a function of control travel to check linearity. |
| Engine Start/Stop Rotor Engagement/Shutdown | Time history of throttle position, engine torque, rotor torque, rotor speed, turbine inlet temperature, gas generator speed and fuel flow | Use video tape coverage (with voice) of pilot going through turnup and shutdown checklists. Qualitative comments on gage/instrument movement/function should be recorded for each affected system. |
| Ground-Handling Characteristics | Control positions and pitch attitude during ground taxi for specific ground speed, wind speed and direction and surface elevation<br><br>Power increase to start taxiing | Primarily, qualitative comments on ground taxi/turning/braking characteristics. |
| Hover Performance | Hover attitude and control positions<br><br>Rotor and engine power versus gross weight<br><br>Collective control position versus gross weight<br><br>Radar altitude versus engine torque IGE/engine torque OGE<br><br>Rotor power versus engine power<br><br>Time history of control positions, attitudes, and rates for pilot workload analysis | Data required for both OGE and IGE hover heights.<br><br>Similar conditions (including available cues and identical tasks are required in trainer and aircraft. |

| Test | Data Presentation | Remarks |
|---|---|---|
| Slow Speed Performance and Flying Qualities | | |
| Sideward Flight | Control positions, roll attitude, and engine torque versus paced ground speed | Precise measurement of paced ground speed and wind speed and direction required. Critical azimuth data should be obtained during steady winds of approximately 10 kt and 20 kt (5.1 m/sec and 10.2 m/sec). |
| Rearward/Slow Forward Flight | Control positions, pitch attitude, and engine torque versus paced ground speed | |
| Critical Azimuth | Control positions, pitch and roll attitudes, engine torque and wind speed versus relative wind azimuth | |
| Vertical Climb Performance | Rate of climb versus engine torque<br><br>Collective position versus engine torque | Record engine torque required to hover OGE before commencing climb. Use torque increments above this value. |
| Airspeed/Altimeter Calibration | Airspeed position error for level flight, climbs, and descent<br><br>Altimeter position error for level flight | |
| Engine Performance | | |
| Test Cell Data<br><br>Power Checks | Corrected engine shaft horsepower, corrected gas generator speed, corrected fuel flow, corrected specific fuel consumption versus corrected turbine inlet temperature | |
| Engine Dynamics<br><br>Selected throttle movements covering full range of control<br><br>Response to trim system actuation<br><br>Response to automatic load sharing system operation | Time history of throttle position, engine torque, rotor speed, fuel flow, gas generator speed, and turbine inlet temperature | From time histories determine lags, overshoots, scheduling, static and transient droop. |

| Test | Data Presentation | Remarks |
|---|---|---|
| Level Flight Performance and Trimmed Control Positions | Referred rotor power versus referred true airspeed for a full range of referred gross weights (can also use nondimensional presentation)<br><br>Individual rotor power versus calibrated airspeed<br><br>Ratio of main rotor power to engine power versus calibrated airspeed<br><br>Control positions, pitch attitude, sideslip, and engine torque versus calibrated airspeed | Data should be collected for ball-centered flight. The effects of sideslip on power should be determined. Drag increments should be determined for configuration changes (i.e., external stores, door/hatches open, etc.). Data should be combined with slow speed performance data to form three dimensional power required curve. |
| Climb and Auto Performance and Trimmed Control Positions | Rate of climb and descent versus calibrated airspeed<br><br>Control positions and pitch attitude versus calibrated airspeed | |
| Power Effects | Control positions, pitch attitude, and cockpit vertical velocity versus engine torque | |
| Static Longitudinal Stability | Longitudinal stick force, stick position, and pitch attitude versus calibrated airspeed | Power fixed at given trim condition. |
| Dynamic Longitudinal Stability | | |
| Short Term | Time history of angular acceleration, load factor, rate and attitude response to control doublet, and pulse inputs | From time histories, determine period, frequency and damping of oscillation or time to half (double) amplitude. |
| Long Term | Time history of pitch attitude and airspeed response to slow and fast starts | Trainer tests should be conducted on motion to induce effects of control inertia and/or dynamics. |
| Static Lateral-Directional Stability | Control positions, bank angle, ball position, rate of descent, and indicated airspeed versus sideslip | Use steady heading sideslip test technique. |

| Test | Data Presentation | Remarks |
|---|---|---|
| **Dynamic Lateral-Directional Stability** | | |
| Lateral and Pedal Control Doublets and Pulse Inputs | Time history of control positions, angular accelerations, rates, and attitudes | From time histories, determine period, frequency, and damping of oscillation or time to half (double) amplitude. |
| Cyclic and Pedal Only Turns | Time history of control positions, rates, and attitudes | |
| Spiral Stability | Time history of bank angle | |
| Release from Steady Heading Sideslips | Time history of control positions, sideslip, heading, yaw rate, roll attitude, roll rate, and airspeed | |
| **Maneuvering Stability**<br>Constant Altitude<br>Constant Power | Longitudinal stick force and stick position versus load factor or bank angle | Document control force relieving functions if applicable, and account for this feature in test procedure. |
| **Control Response**<br>Step Control Inputs | Time history of control positions, angular accelerations, rates, and attitudes. Also, present load factor and airspeed (except hover) for longitudinal inputs and load factor for collective inputs. Minimum data to include hover, normal cruise, and fast cruise for multiple sized inputs. | Emphasize overlaying aircraft and simulator time history control response data for comparison. Note maximum acceleration/rate, time to reach maximum acceleration/rate and initial acceleration/rate lag to control step input. Document cross coupling resulting from single axis control step inputs. Document basic airframe characteristics and repeat for each appropriate mode of AFCS operation. |
| **Autorotational Flying Qualities** | | |
| Auto Entry | Time history of control positions, throttle position engine torque, rotor speed, attitudes, and rates | Control fixed until rotor speed decay or attitude change requires recovery. |
| Full Autos<br>Power Recovery | Time history of control positions, throttle position, engine torque, rotor speed, rates, attitudes, sideslip, airspeed, ground speed (Doppler), pressure altitude, radar altitude, and load factor | Record wind speed and direction during test. |
| R/D Parameter Isolation | | Determine effect of rotor speed, sideslip, and bank angle on rate of descent during autorotation from cockpit gauges. |

| Test | Data Presentation | Remarks |
|---|---|---|
| Vibration | Vibration amplitude versus frequency for given condition (airspeed and loading)<br><br>Also amplitude versus calibrated airspeed for given frequency | Record vibration data for pilot and copilot station for all flight regimes. |
| Stall | Stall boundary as a function of airspeed, rotor speed, density altitude, and loading condition | Qualitative comments on vibration and attitude response to stall and control sequencing required to reduce/aggravate the condition. |
| AFCS Evaluation | Document pilot workload required for identical tasks under each mode of AFCS operation<br><br>Repeat appropriate tests under each mode of AFCS operation | Design tests to evaluate each mode of the AFCS. |

APPENDIX D

Table I

Instrumentation
SH-3H BuNo 148977

| Parameter | Characteristic | Recording Device (1) | Output Device (2) |
|---|---|---|---|
| Longitudinal Cyclic Pos. | Percent from Full Fwd | Data Tape Recorder/Pilot | Cockpit Indicator |
| Lateral Cyclic Pos. | Percent from Full Left | Data Tape Recorder/Pilot | Cockpit Indicator |
| Dir. Pedal Pos. | Percent from Full Left | Data Tape Recorder/Pilot | Cockpit Indicator |
| Collective Pos. | Percent from Full Down | Data Tape Recorder/Pilot | Cockpit Indicator |
| Tail Rotor Pitch | Deg | Data Tape Recorder/Pilot | Cockpit Indicator |
| Pitch Attitude | Deg Up or Down | Data Tape Recorder | Attitude Gyro |
| Roll Attitude | Deg Left or Right | Data Tape Recorder | Attitude Gyro |
| Yaw Attitude | Deg Left or Right | Data Tape Recorder | Directional Gyro (Self-Caging) |
| Pitch Rate | Deg/Sec Up or Down | Data Tape Recorder | Rate Gyro |
| Roll Rate | Deg/Sec Left or Right | Data Tape Recorder | Rate Gyro |
| Yaw Rate | Deg/Sec Left or Right | Data Tape Recorder | Rate Gyro |
| Pitch Ang. Accel. | $Deg/Sec^2$ Up or Down | Data Tape Recorder | Angular Accelerometer |
| Roll Ang. Accel. | $Deg/Sec^2$ Left or Right | Data Tape Recorder | Angular Accelerometer |
| Yaw Ang. Accel. | $Deg/Sec^2$ Left or Right | Data Tape Recorder | Angular Accelerometer |

| Parameter | Characteristic | Recording Device[1] | Output Device[2] |
|---|---|---|---|
| Load Factor | g | Pilot | Computed |
| Sideslip | Deg Left or Right | Data Tape Recorder/Pilot | Cockpit Indicator |
| Radar Alt. | Ft | Data Tape Recorder/Pilot | A/C Gauge (Rad. Alt.) |
| Ground Speed | Kt | Data Tape Recorder/Pilot | A/C Gauge (Doppler) |
| Drift Angle | Deg | Data Tape Recorder/Pilot | A/C Gauge (Doppler) |
| Turn and Slip | Needle and Ball Pos. | Pilot | A/C Gauge |
| Vertical Velocity | Ft/Min | Pilot | A/C Gauge |
| Airspeed | Kt | Pilot | Cal. A/C Gauge |
| Torque (1 and 2) | Percent | Pilot | Cal. A/C Gauge |
| Altitude (Baro.) | Ft | Pilot | A/C Gauge |
| OAT | Deg, C | Pilot | Cal. A/C Gauge |
| Time | Sec | Pilot | Hand-held Stopwatch |
| Wind | From Deg Mag/Vel, Kt | Pilot | Hand-held Anemometer or Tower Report |
| $N_R$ | Percent | Pilot | A/C Gauge |
| $N_f$ (1 and 2) | Percent | Pilot | A/C Gauge |
| $N_g$ (1 and 2) | Percent | Pilot | A/C Gauge |
| $T_5$ (1 and 2) | Deg, C | Pilot | A/C Gauge |
| Gross Weight | Lb | Pilot | Computed |
| Fuel Load<br>Front<br>Center<br>Aft | Lb | Pilot | A/C Gauge |
| External Stores | Loaded/Unloaded | Pilot | As Selected |
| Long. CG | In. | Pilot | Computed |
| T/R Power | Ft-Lb | - | (Ref. Data) |
| M/R Power | Ft-Lb | - | (Ref. Data) |
| Control Force | Lb | Pilot | Hand-held Force Gauge |
| Fuel Flow | Lb/Min | - | (Ref. Data) |
| Event Marker | Step Signal | Data Tape Recorder | Cockpit Control |

NOTES: (1) Engineering units tape will be created from FM tape in aircraft instrumentation package. Computer plotting will be done where applicable.

(2) Equipment indicated is special instrumentation unless identified as aircraft equipment.

APPENDIX D

Table II

Instrumentation
Device 2F64C

| Parameter | Characteristic | Recording Device (1) | Output Device (2) (3) |
|---|---|---|---|
| Longitudinal Cyclic Pos. | Percent from Full Fwd | Analog Recorder/Instructor | Console Page |
| Lateral Cyclic Pos. | Percent from Full Left | Analog Recorder/Instructor | Console Page |
| Dir. Pedal Pos. | Percent from Full Left | Analog Recorder/Instructor | Console Page |
| Collective Pos. | Percent from Full Down | Analog Recorder/Instructor | Console Page |
| Tail Rotor Pitch | Deg | Analog Recorder/Instructor | Console Page |
| Pitch Attitude | Deg Up or Down | Analog Recorder/Instructor | Console Page |
| Roll Attitude | Deg Left or Right | Analog Recorder/Instructor | Console Page |
| Yaw Attitude | Deg Left or Right | Analog Recorder/Instructor | Console Page |
| Pitch Rate | Deg/Sec Up or Down | Analog Recorder/Instructor | Console Page |
| Roll Rate | Deg/Sec Left or Right | Analog Recorder/Instructor | Console Page |
| Yaw Rate | Deg/Sec Left or Right | Analog Recorder/Instructor | Console Page |
| Pitch Ang. Accel. | $Deg/Sec^2$ Up or Down | Analog Recorder | - |
| Roll Ang. Accel. | $Deg/Sec^2$ Left or Right | Analog Recorder | - |
| Yaw Ang. Accel. | $Deg/Sec^2$ Left or Right | Analog Recorder | - |
| Load Factor | g | Pilot | Computed |
| Sideslip | Deg Left or Right | Analog Recorder/Instructor | Console Page |
| Radar Altitude | Ft | Analog Recorder/Instructor | Console Page |
| Ground Speed | Kt | Analog Recorder/Instructor | Console Page |
| Drift Angle | Deg | Analog Recorder/Instructor | Console Page |
| Turn and Slip | Needle and Ball Pos. | Instructor | Console Page |
| Vertical Velocity | Ft/Min | Instructor | Console Page |
| Airspeed | Kt, Observed<br>Kt, Calibrated | Pilot<br>Instructor | A/C Gauge<br>Console Page |
| Torque (1 and 2) | Percent | Instructor | Console Page |
| Altitude (Baro.) | Ft | Instructor | Console Page |
| OAT | Deg, C | Instructor | Console Page |
| Time | Sec | Pilot | Hand-held Stopwatch |
| Wind | From Deg Mag/Vel, Kt | Instructor | Console Page |
| $N_R$ | Percent | Instructor | Console Page |
| $N_f$ (1 and 2) | Percent | Instructor | Console Page |

| Parameter | Characteristic | Recording Device[1] | Output Device[2][3] |
|---|---|---|---|
| $N_g$ (1 and 2) | Percent | Instructor | Console Page |
| $T_5$ (1 and 2) | Deg, C | Instructor | Console Page |
| Gross Weight | Lb | Instructor | Console Page |
| Fuel Load<br>Front<br>Center<br>Aft | Lb | Instructor | Console Page |
| External Stores | Loaded/Unloaded | Instructor | Console Page |
| Long. CG | In. | Instructor | Console Page |
| T/R Power | Ft-Lb | Instructor | RMM |
| M/R Power | Ft-Lb | Instructor | RMM |
| Control Force | Lb | Pilot | Hand-held Force Gauge |
| Fuel Flow (1 and 2) | Lb/Min | Instructor | RMM |

NOTES: (1) Analog Recorder wired directly to computer D/A output source for on-scene analysis. FM data tape recorder connected to same source for making engineering units tape (as required) at NAVAIRTESTCEN CSD.

(2) Remote Memory Monitor (RMM) can be used to monitor any parameter in the program.

(3) All simulated instruments are calibrated and meet at least aircraft standards. Each gauge will be checked and verified against commanded computer value. Cockpit parameters may be taken from console page to eliminate gauge error and for simplicity.

DISTRIBUTION:

| | |
|---|---|
| NAVAIRTESTCEN (CT-02) | (1) |
| NAVAIRTESTCEN (CT-84) | (1) |
| NAVAIRTESTCEN (CT-08) | (1) |
| NAVAIRTESTCEN (SA-01) | (1) |
| NAVAIRTESTCEN (SY-01) | (1) |
| NAVAIRTESTCEN (AT-01) | (1) |
| NAVAIRTESTCEN (TP-01) | (5) |
| NAVAIRTESTCEN (RW-01) | (50) |
| DDC | (12) |
| NAVAIR (AIR-413) | (5) |
| NTEC (Code 222) | (20) |